Technical White Paper

Leveraging Single-Pair Ethernet in Building Automation

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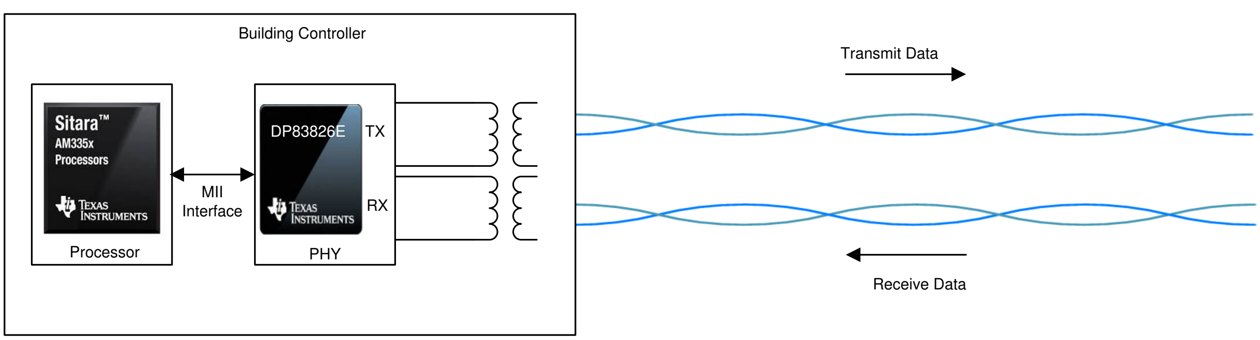
Ethernet has become a mainstream communications protocol, at the top of the control pyramid in building automation. Recently, the Institute of Electrical and Electronics Engineers (IEEE) defined a new Ethernet standard, IEEE 802.3.cg for 10 Mb/s operation and associated power delivery over a single balanced pair of conductors. Because a single-pair cable can now support both data and power, adoption of the standard can lead to significant cost savings and easier installation in building automation applications.

There are numerous efforts to take Ethernet to the edge devices. Multiple communication networks currently exist in building automation – for example, heating, ventilation and air-conditioning (HVAC) applications use Modbus, access control uses BACnet, lighting uses LonWorks and fire safety uses Ethernet. This fragmentation of networks requires the use of gateways to perform protocol conversion to unite merge networks at the top of the building automation control pyramid. End users must in turn manage complex systems.

Reasons for the existence of various communication networks include the need for longer distances, multidrop connectivity, powering scheme and support for unique protocols. Single-pair Ethernet (SPE) can address many of the above said reasons. Having Ethernet to the edge devices offers benefits such as direct accessibility for the control system, status updates, predictive maintenance, standardized hardware and interoperability across various systems.

Overview of SPE

Standard Ethernet uses simplex communication with independent cables for transmitting and receiving data, as *Standard Ethernet Interface for 10/100 Mbps* shows.



Standard Ethernet Interface for 10/100 Mbps

SPE is broadly classified into three categories:

- IEEE 802.3.cg (10 Mbps)
- IEEE 802.3.bw (100 Mbps)
- IEEE 802.3.bp (1,000 Mbps)

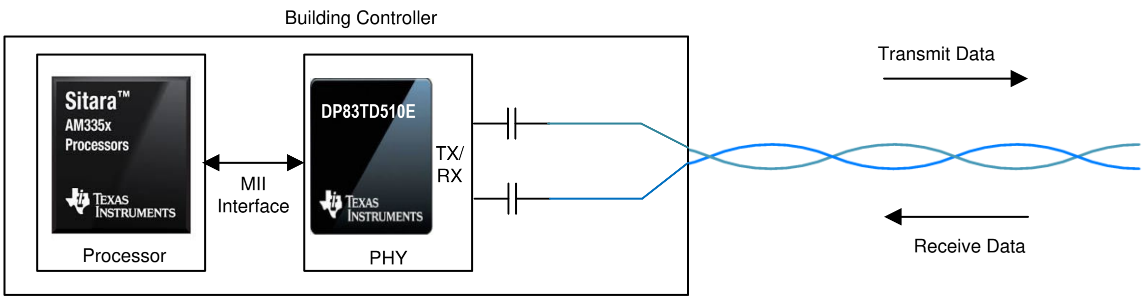
IEEE 802.3cg has two more classifications:

- Long and short cable lengths reach over a single balanced pair of either shielded or unshielded wire. 10BASE-T1L: IEEE 802.3 Physical Layer specification for a 10 Mb/s Ethernet local area network over a single balanced pair of conductors up to at least 1000 m reach (long reach using 18 AWG wire for point to point connection).
- 10BASE-T1S: IEEE 802.3 Physical Layer specification for a 10 Mb/s Ethernet local area network over a single balanced pair of conductors up to at least 15 m reach (short reach using 24–26 AWG wire with multidrop connection).

This article covers use cases for 10BASE-T1L, which offers up to 10 Mbps data rate over 1,000-m distances in building automation systems.

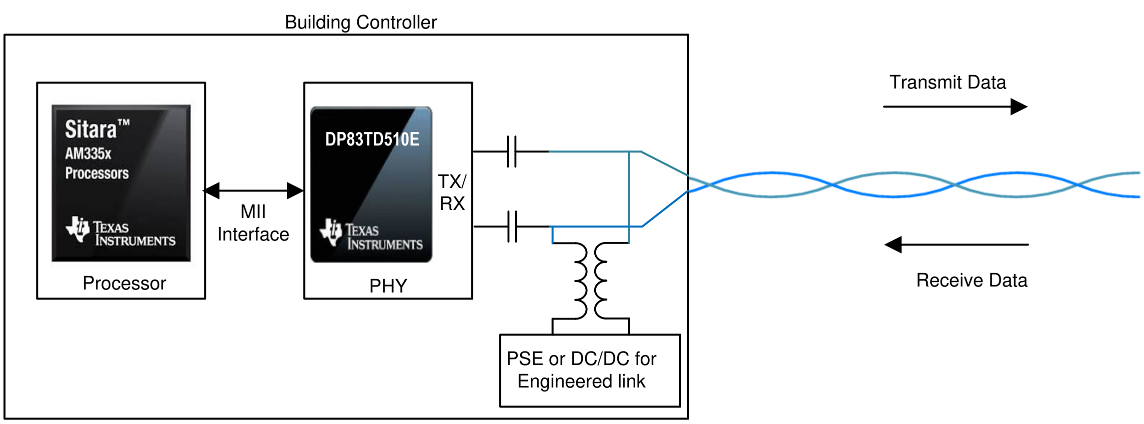
The 10BASE-T1L physical layer (PHY) operates using full-duplex communications over a single balanced pair of conductors with an effective data rate of 10 Mbps simultaneously in each direction. A 10BASE-T1L PHY, such as the DP83TD510E, uses three-level pulse amplitude modulation (PAM3), transmitted at 7.5 megabaud on the link segment. A 33-bit scrambler can help improve electromagnetic compatibility. MII transmit data (TXD<3:0>) are encoded together using four-binary three-ternary (4B3T) encoding, which keeps the running average (DC baseline) of the transmitted PAM3 symbols within bounds. Using the management data input/output interface to set the transmitter output voltage of the 10BASE-T1L PHY to 1.0 Vpp or 2.4 Vpp differentials will help achieve a longer communication distance over different cables.

As *SPE Interface for 10 Mbps Using the DP83TD510E* shows, SPE uses echo cancellation to achieve full duplex communication, along with multilevel signaling and equalization to improve signal quality and achieve the required data rate over a single-pair cable. There is no difference in the interface between the processor and the PHY; however, within the PHY, the transmit and receive sections of the Medium Dependent Interface require modification as outlined above to enable single-pair operation.



SPE Interface for 10 Mbps Using the DP83TD510E

SPE also enables sending power over data lines (PoDL) along the same single-pair cable through a low-pass filter like the one shown in *PoDL Example*.



PoDL Example

The table in the following image lists the various power classes supported by the IEEE 802.3.cg standard. The maximum power deliverable to the load is 52 W and is defined under Class 15. Power classes below 10 are covered by IEEE 802.3.bu.

Table 104–1a—Class power requirements matrix for PSE, PI, and PD for classes 10 through 15

Class	10	11	12	13	14	15
$V_{PSE(max)}$ (V)	30	30	30	58	58	58
$V_{PSE\_OC(min)}$ (V)	20	20	20	50	50	50
$V_{PSE(min)}$ (V)	20	20	20	50	50	50
$I_{PI(max)}$(mA)	92	240	632	231	600	1579
$P_{class(min)}$ (W)	1.85	4.8	12.63	11.54	30	79
$V_{PD(min)}$ (V)	14	14	14	35	35	35
$P_{PD(max)}$ (W)	1.23	3.2	8.4	7.7	20	52

Power Classes Supported by the IEEE 802.3.cg Standard

Benefits of SPE

Transitioning to SPE has multiple benefits, starting from installation to managing an entire building using a single communication network. Its benefits result in a lower total cost of ownership and a better return on investment in building automation systems. For example:

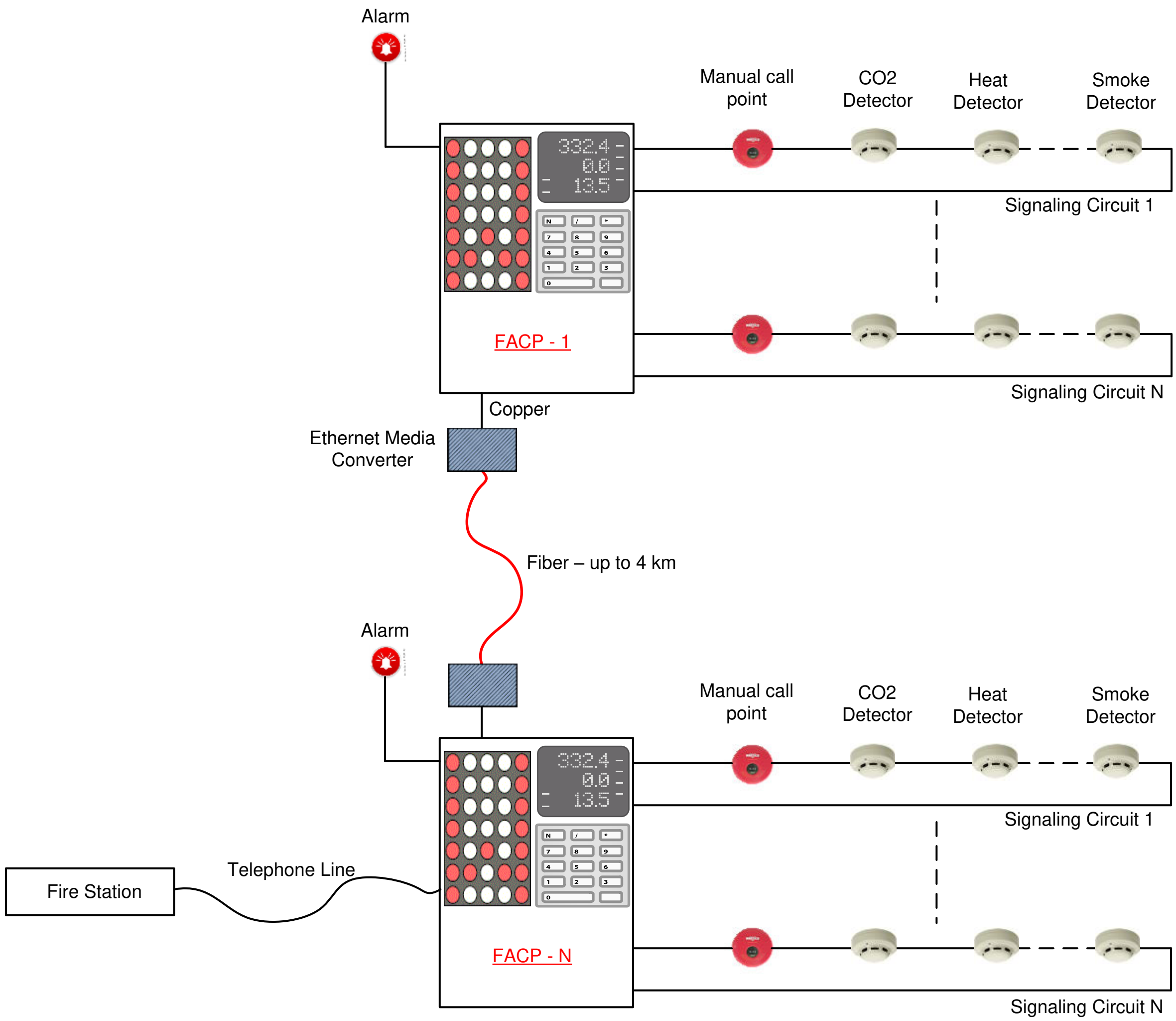
- Having Ethernet connectivity brought to the edge eliminates the need for additional gateways, which simplifies systems by only requiring a single communication network.
- PoDL eliminates the need for a separate power cable, which simplifies wiring in building automation systems.
- With just one pair of wires, the cabling becomes cheaper and lighter, making overhead wiring easier.
- Faster and easier installation reduces the cost of labor.
- Improved bandwidth compared to existing field bus networks provides the flexibility to implement features such as predictive maintenance.
- 10BASE-T1L offering communication distance of 1000 m at 10Mbps data rate helps replace costlier fiber cables and enable more data transfer.

The following section explains how SPE can be implemented and the associated benefits for various building automation applications.

Fire Safety Applications

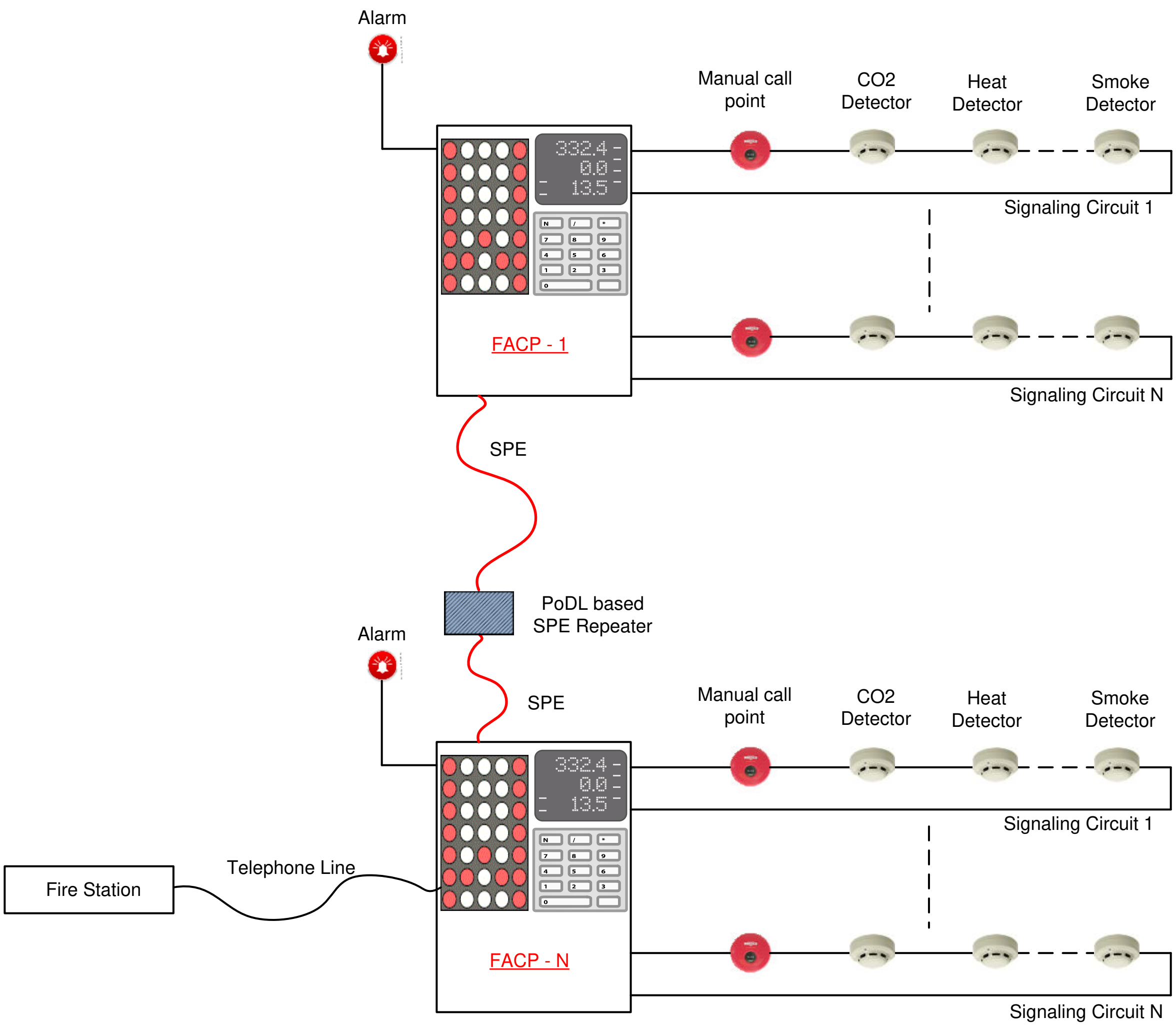
Fire alarm control panels (FACPs) connect to various heat, smoke and gas detectors. These sensors, connected together in the signaling loop, generate an alarm in case of accidents and FACPs may communicate to fire stations through a telephone network. An FACP often supports multiple signal loops in order to facilitate splitting into various zones or floors for easy identification.

Each building can have multiple FACPs, depending on the number of floors and sensors. When a facility like a large residential complex, office, school or shopping mall expands, there is often a need to interconnect FACPs across buildings as far as 3 to 4 km apart through Ethernet, using either copper or fiber wires. Ethernet based on 100BASE-TX/10BASE-T) require multiple repeaters to bridge these distances, in which case powering them can be a challenge. Another option is to transition to fiber cables, which require media converters (copper to fiber) at both ends. *Traditional Architecture – Fiber Connectivity Between FACPs* depicts an example system.



Traditional Architecture – Fiber Connectivity Between FACPs

Both of the previously-described options result in expensive systems. SPE can solve both challenges for distances up to 1 km; and for systems with greater distances, you can use repeaters powered through PoDL. PoDL eliminates the need of external power supply, further simplifying the system. *Architecture Using SPE Between FACPs* depicts a fire safety system using SPE.



Architecture Using SPE Between FACPs

Vertical Transportation Applications

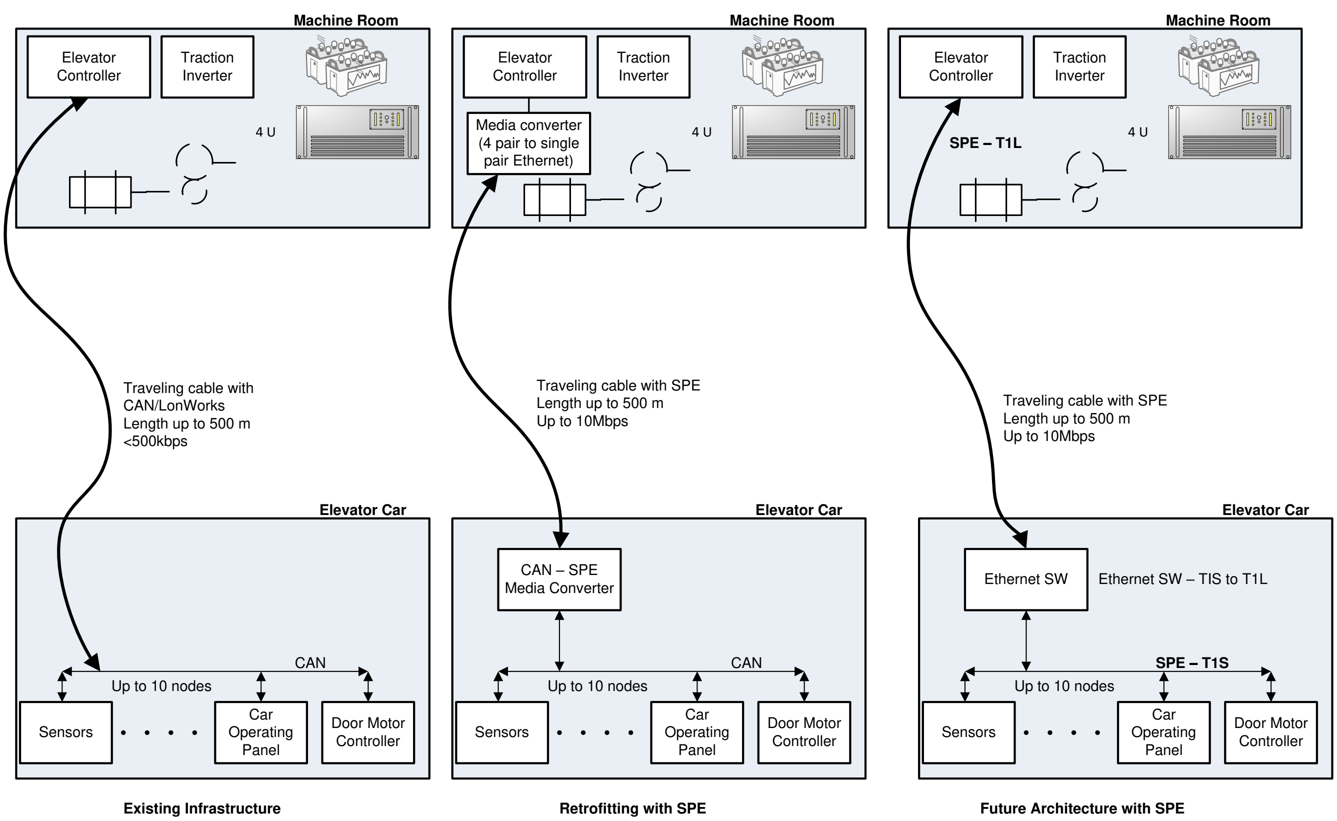
Elevators are a complex system. The main communication link between a moving elevator car and the machine room controller is through a travelling cable. The length of this cable can be anywhere from 10 to 500 m or longer, depending upon the height of the building. Controller Area Network (CAN) and LonWorks are common protocols used for elevator systems given their low speed requirements and required cable distances.

Cable reliability over a period of several years is important given the amount of stress it experiences during operation. As the elevator moves up and down, the cable needs to bend, which is not ideal for optical fiber cabling, so most elevator cables are made of copper. And given the cable length, standard Ethernet is not suitable because it can't work beyond 100 m.

Now, with SPE offering 1-km distances and speeds up to 10 Mbps, it's a good choice for next-generation elevator designs. The need for higher data rates between the elevator car and elevator controller is arising from:

- Streaming video content from inside elevator cars back to machine room.
- Relay of advertisements from machine room to elevator car.
- Sending more data to the elevator controller from various sensors, along with data from equipment within the car to be used for predictive maintenance.

Upgrading existing elevators is equally as important as designing new elevators with more advanced features. One way to resolve retrofitting challenges is to have media converters like CAN to SPE inside the elevator car and SPE to standard Ethernet or CAN for the elevator controller. For next-generation systems, the elevator controller could incorporate a built-in SPE PHY 10BASE-T1L and the equipment within the car would be connected through SPE PHY 10BASE-T1S. The elevator car would also have a built-in 10BASE-T1S or 10BASE-T1L Ethernet switch to interface the car with the elevator controller. Emergency lights and communication systems within the elevator car could be powered through PoDL to ensure that there is no disruption of power.

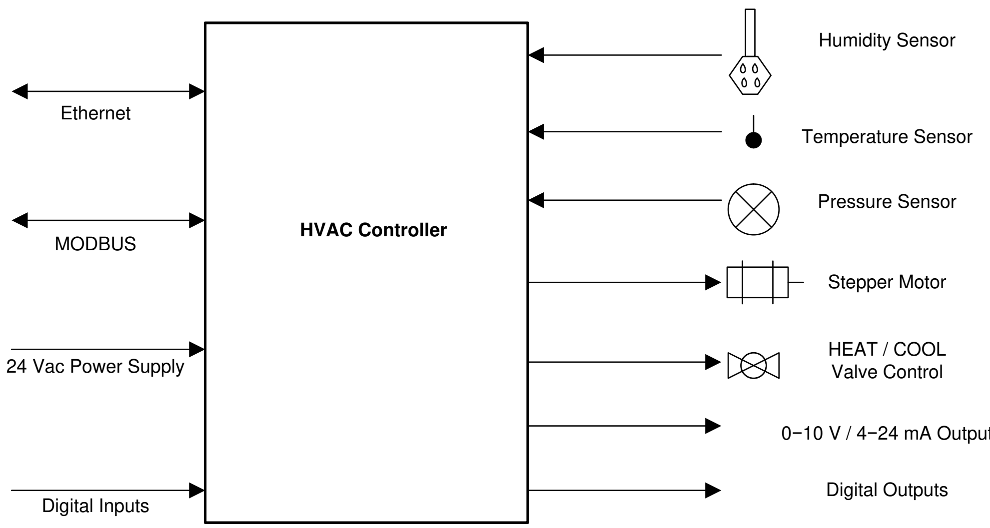


Elevator Car-to-Machine Room Communication

HVAC Applications

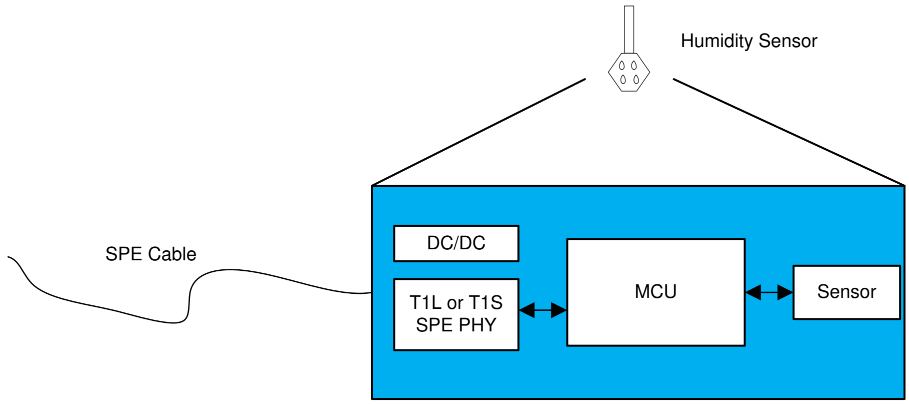
HVAC controllers are being unified in order to control a rooftop unit, chiller control unit, air-handling unit and more. HVAC controllers use standard Ethernet to interface with higher-level building automation systems such as the building management system, as well as to daisy-chain multiple HVAC controllers. In order to maintain network connectivity when any of the HVAC controllers are powered off, electromechanical relays short the Ethernet signals at the input and output ports.

HVAC controllers have multiple analog, digital or field bus interfaces to communicate or control multiple sensors that measure parameters like temperature, humidity, and pressure (see *HVAC Controller Interface*). The sensors could be analog output with loop power, or support 0- to 10-W/4- to 20-mA output with separate power. HVAC controllers can also connect to actuators like dampers, fans and stepper motor drives through communication interfaces or analog connections. Having SPE connectivity from the controller to the sensors and actuators would simplify installation with only two wires and enable access to devices at the edge.



HVAC Controller Interface

SPE-Based Sensing illustrates one example implementation using a humidity sensor, where the I2C interface connects to a microcontroller (MCU) with built-in media access control (MAC). SPE PHY (10BASE-T1L or 10BASE-T1S) interfaces to the built-in MAC of the MCU, while PoDL with a DC/DC converter powers the entire circuit. This architecture offers multiple benefits, including standardization of sensor connectors, reusable hardware, sensor and hardware diagnostics and calibration.



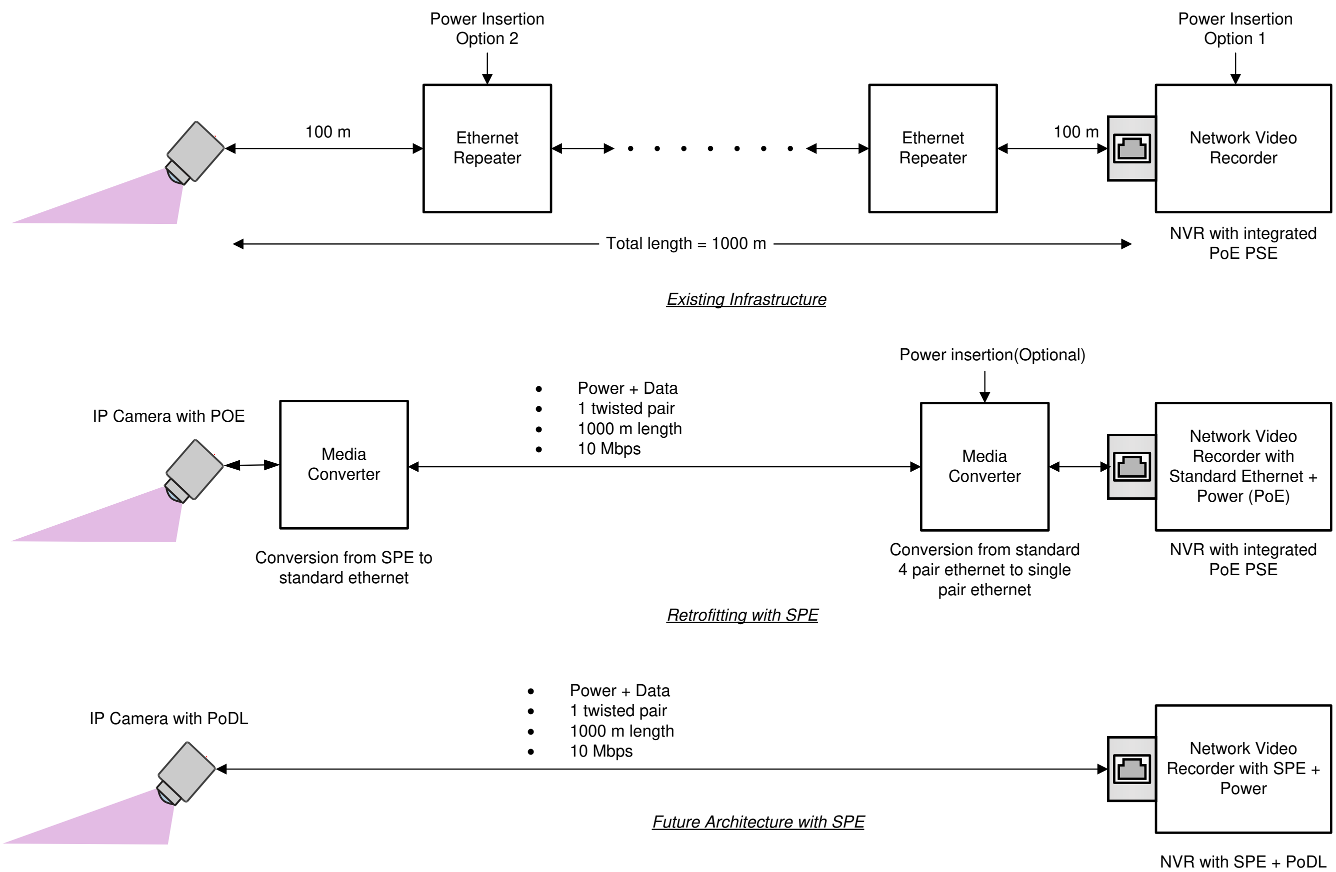
SPE-Based Sensing

Having multiple SPE ports within a HVAC controller to interface various sensors and actuators would require an application-specific integrated circuit to implement Ethernet switch functionality, which is readily available.

Video Surveillance Applications

Outdoor Internet Protocol (IP) network cameras are often installed at the perimeter of buildings to ensure the continuous capture of video and to generate alarms when security is breached quickly enough to give security officers sufficient time to react. The distance from these cameras to a network video recorder could be 1 km or more, and bridging this distance with standard Ethernet involves repeaters or the use of fiber cabling. With efficient encoding systems like H.264 and H.265, the data-rate requirement drops to under 10 Mbps, even with 4-MP sensors that have a 30-fps rate, see *IP Network Camera Connectivity*.

Future IP camera products are expected to support SPE, which will facilitate easier installations, as will network video recorders offering a power-sourcing equipment port. Classes 8 and 9 (48-V regulated power-sourcing equipment) or Classes 14 and 15 (50- to 58-V maximum) could support the required power levels for an IP camera, which might need as much as 52 W of power to operate. This power would be sufficient for most camera systems, even those with built-in heaters. For buildings that need upgrades, an intermediate solution would be to use standard Ethernet-to-SPE converters.



IP Network Camera Connectivity

Summary

SPE, either stand-alone (data only) or together with power, offers numerous opportunities in building automation. Until the ecosystem is fully developed, however, there is still a need for media or protocol converters to upgrade existing systems, as well as challenges associated with the reuse of existing cables (unshielded, no twisting, wire gauge) and connectors, which may not offer the full distance or speed as defined in 802.3cg. But this will not be a major hindrance, as the future benefits outweigh the constraints. Power-sourcing equipment and power-delivery devices for SPE are expected to be released in the coming years; until then, an engineered link will power devices at the edge. You can also expect to see building automation products supporting SPE with seamless integration.

References

- IEEE Standard for Ethernet